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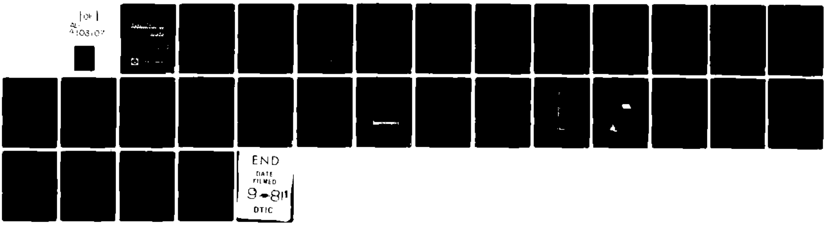

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This report has discussed various concepts for energy conservation in Navy shore facilities which can be achieved through architectural and structural design decisions. These concepts include earth-sheltered structures, thermal mass concepts, passive solar designs, and exploitation of existing technology. Advantages and disadvantages of the systems were discussed in qualitative terms. Where possible, specific data and equations were presented to

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INTRODUCTION

This report presents the findings of a study which is part of the Navy Shore Facilities Energy Research and Development Program. The program is sponsored by the Naval Material Command, Energy and Natural Resources Research and Development Office (MAT-08E) through the Naval Facilities Engineering Command. The Civil Engineering Laboratory is the lead laboratory for the program. The key strategies of the program are energy conservation and alternative energy systems. This study relates most closely to the first strategy, which involves eliminating inefficient and wasteful use of energy and applying more energy-efficient systems.

Problem

Energy conservation in shore facilities can be approached by considering each facility as an energy-using system composed of several subsystems, each of which is responsible for a portion of the total system energy demand. The focal point of this study is the subsystem comprising the structural form of the facility and its influence on overall energy requirements. The extent to which the structural form permits energy to enter or escape from a facility has a significant effect on other subsystems such as heating, cooling, and lighting. The basic problem addressed by this study is the identification and evaluation of structural and architectural concepts which reduce energy requirements of facilities.

A frequently used approach to reducing heat loss or gain in buildings is to reduce heat flow by insulating or by minimizing air infiltration or exfiltration. These are effective and efficient strategies for energy conservation, and they are discussed in a separate section of this report. However, as energy costs rise and nonrenewable fuels become scarce, many innovative concepts are being proposed for energy-conserving structures. These systems must be evaluated with respect to their merits as generic concepts and with respect to benefits obtainable in specific applications. It is the intent of this study to describe these concepts in sufficient qualitative and quantitative detail to permit benefit versus cost evaluations for specific applications.

Scope

This study was confined to architectural and structural concepts for reducing energy use in facilities. The evaluation of innovative heating, ventilating, or air conditioning systems which are part of the electrical and mechanical design of facilities is not discussed. Concepts discussed here are basically passive systems which, at most, may require occupants to perform a few manual operations or to turn on simple motors.

Active solar energy systems which require collectors, circulating fluid, or heat exchangers are specifically excluded because they could actually form the basis of an entire separate study. Other concepts which exploit similar thermodynamic principles as some systems described, but which are more appropriately categorized as active systems may be mentioned briefly, but their operation will not be discussed in detail.

Concepts which will be discussed are in various stages of development at the time of this writing. A few ideas exist only in theory. Others may have limited subscale or laboratory data to verify the basic principles. Other concepts have been developed to the extent that in-service experimental or demonstration facilities exist. Some of the concepts in the commercial sector are just beginning to penetrate the marketplace, while others are well established.

This report will discuss in qualitative terms and, where possible, quantitative terms, the possible Navy applications and benefits of the various concepts. Applications to specific Navy building categories and potential benefits with regard to energy and life-cycle cost savings will be discussed. Negative aspects will also be discussed to permit rational evaluations of net benefits versus costs.

CONCEPTS

The various structural and architectural concepts that contribute to low energy usage, hereinafter called low energy structures concepts, can be categorized into four general groups. These groups are roughly categorized by the principles on which the concepts are based. The placement of a specific concept within a given group was based solely on the author's judgment.

The general categories and the order in which they will be discussed are earth-sheltered structures, thermal mass systems, passive solar design, and exploitation of existing technology. Within each category specific concepts will be discussed with respect to their benefits, liabilities, and possible applications. Historical background, stage of present development, and future prospects will be given wherever applicable.

Earth-Sheltered Structures

The concept of earth-sheltered structures may be innovative in today's technology, but it is not new. A brief history of earth-covered structures was compiled by Labs (Ref 1). Historical structures included dwellings, churches, and entire towns.

Modern examples of earth-sheltered architecture encompass an even broader range of facilities. Ethicon, the world's largest supplier of surgical sutures, operates an underground manufacturing plant in San Angelo, Tex. Lake Worth Junior High School in Ft. Worth, Tex., is only one example of several underground schools; Terraset Elementary School in Reston, Va., is another (Ref 2). The museum and supporting facilities of the Jefferson National Expansion Memorial are located underground beneath the legs of the Gateway Arch near the waterfront in St. Louis, Mo. A two-level restaurant/nightclub with direct auto access was constructed in Italy. In Death Valley National Monument in California a reverse osmosis water treatment plant has been placed underground to reduce visual impact and to reduce temperatures. These examples demonstrate that earth-sheltering concepts can be used for a variety of facility types.

Earth-sheltered structures can be categorized into three general types: fully buried, partially buried, and bermed. Fully buried structures are those for which the only exposure to the surface is at entrance passageways or shafts. The most common form of these facilities is a tunnel entry into the side of a mountain, a mesa, or a bluff. A well-known example of this form is the International Trade Center in Kansas City, where a world trade zone, precision instrument manufacturer, and several leased storage facilities are located. Partially buried structures are those in which a significant portion of the structure, possibly including the roof, is in direct contact with the earth but one or more sides are exposed to the surface environment. Bermed structures are similar to partially buried structures except that the main floor is located at the surface and compacted earth is placed around the periphery.

Earth shelter in any of the above forms contributes to energy efficiency primarily through reduction of transmission losses. This effect is evident from the one-dimensional, steady-state heat transmission equation for homogeneous materials (Ref 3)

$$\dot{Q} = -K A \frac{\Delta t}{w} \tag{1}$$

where $\dot{Q}$ = rate of heat transfer

K = thermal conductivity

A = area through which heat flows

Δt = temperature difference between surfaces

w = distance through which heat flows

Placing soil or rock in contact with the exterior wall surface significantly reduces the Δt across the wall. For portions of structures below the ground level, the phenomenon is analogous to placing the structure in a constant temperature reservoir. Data from the University of Minnesota and Rutgers University have shown that, even at shallow depths, seasonal and diurnal temperature fluctuations are very small, and these fluctuations decrease at greater depths (Ref 4). Thus, in cold climates, where winter design temperatures for exterior air may be on the order of 0°F, exterior design temperature for an earth-sheltered building would be on the order of 50°F. The Δt would be 18°F rather than 68°F. Similar benefits accrue in the summer when ground temperatures are less than air temperatures, and less cooling energy is necessary.

The year-round exterior design temperature can be estimated as being equal to the annual average air temperature. This approach is, however, an oversimplification of the true behavior. Ground temperatures are more appropriately functions of time of year, depth, and soil type. The simplest equation that reasonably describes the function is (Ref 5):

$$T_{(x,t)} = T_m - A_s e^{-x\left(\frac{\pi}{365\ a}\right)^{1/2}} \cos\left\{\frac{2\,\pi}{365}\left[t - t_o - \frac{x}{2}\left(\frac{365}{\pi\ a}\right)\right]^{1/2}\right\} \qquad (2)$$

where $T_{(x,t)}$ = temperature of the ground at depth x in feet on day t of the year.

T_m = mean annual ground temperature

A_s = annual temperature amplitude at the surface (x = 0)

t = time of year, in days.

t_o = phase constant, day of minimum surface temperature.

a = thermal diffusivity of soil, in ft^2/day.

The value of T_m may be estimated as 2 to 3°F above the average annual air temperature and the value of the thermal diffusivity can be obtained from the ASHRAE Applications Handbook (Ref 6). Equation 2 could be used for a quasi-static analysis of heat flow from buried structures.

Heat flow from earth-sheltered structures is, however, a dynamic phenomenon. The effect is most evident in the analysis of partially buried and bermed structures, where thermal conductivity and specific heat of the soil mass must be considered.

Diurnal and seasonal temperature variations must be considered, because measurements have shown that such an earth-structure system tends to produce a temperature phase lag so that peak ground temperature occurs when the air temperature is approaching a minimum and vice versa (Ref 4). The analysis of these effects can be extremely complex and is generally beyond the scope of the standard building thermal analysis computer programs.

A further means by which earth-sheltered buildings reduce energy requirements is by reducing infiltration and exfiltration heat losses. By their very nature, earth-sheltered buildings must be well sealed to prevent water and moisture intrusion from the surrounding soil or rock. Generally, fewer windows and doors are available as sources of infiltration losses. Although the effect is difficult to quantify without direct measurements on a given building, it is a positive benefit for reducing heat loss. Lack of infiltration may, however, be a disadvantage, because it may force a requirement for positive ventilation just to satisfy respiratory requirements of the occupants (Ref 7).

Earth-sheltered structures provide several benefits which are not related to energy conservation. They tend to have low maintenance costs because little of the exterior surface is exposed to weather. Protection against natural hazards such as tornados and earthquakes may be enhanced. They also provide improved blast and fallout protection relative to surface structures. These are all benefits which are provided without additional expense.

Negative aspects of earth-sheltered structures must also be considered. Their most frequently cited liability is the increased construction costs. Structures must generally be of concrete or masonry, and extreme care must be taken to insure waterproof and moisture-resistant structures. Costs may be prohibitive where the water table is near the ground surface. Situations may also arise where the facility mission requirements are incompatible with earth-shelter concepts. Aircraft control towers and patients' rooms in hospitals are two examples. Earth-sheltered structures must be relatively strong to resist earth pressure loads on the walls or roofs. Requirements for added strength also increase initial costs. These liabilities must all be considered relative to total life-cycle costs and overall energy savings.

The Navy has several facility types which are potential candidates for buried or earth-sheltered concepts. A study of the suitability of various facilities for subsurface siting identified administration buildings, medical facilities, aircraft maintenance facilities, ammunition storage facilities, and miscellaneous storage facilities as prime candidates (Ref 8). The selection criterion was minimum life-cycle cost, but energy usage for surface and subsurface facilities was assumed to be equal. If energy costs were properly included in the analysis, several other facility types would probably also be cost effective.

Thermal Mass Concepts

Thermal mass is the property of a building system or material that permits it to effectively store thermal energy. It is a function of both the specific heat and the mass of a system. Systems with high thermal mass absorb heat slowly and release heat slowly. This property may be exploited to reduce peak heating and cooling requirements. In cold weather, sunlight or waste heat may be stored in the thermal mass system during the day, and the slow release of the heat during the evening will reduce energy requirements for heating. In warm weather, the heating of the thermal mass during the day reduces the cooling requirements, and the absorbed heat is released in the evening when ambient temperatures are lower.

Thermal mass phenomenology can be exploited through several specific concepts. The use of reinforced concrete and concrete masonry structures is the simplest concept. The structural steel and interior elements form the thermal mass of this system. Relatively high mass and moderate specific heat of these materials combine to provide a beneficial thermodynamic condition. Because of the relatively poor insulating properties of these materials, the heat flow analysis must be conducted for dynamic rather than steady-state conditions.

A simplified approach for considering the effects of thermal mass in these systems is the use of the M factor (Ref 9). This factor was developed by conducting a series of dynamic analyses of various wall sections in several different climates. Heat flow was calculated for walls with zero mass and for walls with the same insulation properties but finite mass. The ratio of average heat flow for a finite mass wall to a zero mass wall was defined as the M factor. Thus, the heat flow through a given wall area, A, and temperature gradient, Δt, can be expressed as:

$$\dot{Q} = M\,U\,A\,\Delta t \tag{3}$$

where U is the thermal conductivity or the inverse of the insulation resistance R. The M factor is a function of weight per unit area of the wall and average heating degree-days for the locality considered. Graphs for estimating the value of M are given in Reference 9. This approach has been proposed as a simplified design method for considering and designing thermal mass in structures.

The Brownell house demonstrates that high thermal mass may be obtained without using masonry or concrete for the building envelope (Ref 10). A section of this house is shown in Figure 1. The house contains many energy-conserving features, but the two concepts which are of primary interest to the present study are exterior insulation and a massive central chimney. Exterior walls are of 6-inch by 6-inch posts on 4-foot centers with 3/4-inch pine and 1/2-inch sheet rock exterior to the posts and 4 inches of polyurethane insulation on the outside. The posts and pine sheathing are exposed on the interior. Details are shown in Figure 2. Placing insulation outside the structural wall insures that most of the heat absorbed by the wall will be released to the interior of the building, because the only path to the outside is through the insulation. The central chimney which is almost completely contained by the insulation envelope also stores large amounts of heat. It absorbs heat from sunlight and room air and from combustion gases and smoke.

The Brownell house also utilizes active thermal storage by circulating air through ducts embedded in a sand bed beneath the basement floor. An analysis of the system indicated that the sand bed as constructed was inefficient. More ducts to provide greater interface surface area or more mass, such as using concrete instead of sand, would have improved the system.

Among the most efficient active thermal mass concepts is rock bed storage. In this system, air passes directly through the voids in a coarsely graded rock bed. It is simple, because no ducts are required. It is efficient, because of the large surface-area-to-volume ratio.

Any further discussion of active thermal storage systems is beyond the scope of the present study. Such a restriction limits the discussion to what one report calls natural thermal storage (NTS) systems (Ref 11). Benefits claimed for NTS are:

(1) reduced peak thermal loads

(2) improved performance of space heating equipment

(3) more efficient use of solar gains

(4) extended use of outdoor air for temperature conditioning

(5) potential for use of off-peak electric heating

(6) recovery of waste heat

The same report also identifies the trombe wall as one of the most cost effective forms of NTS. A trombe wall is a relatively massive wall consisting of reinforced concrete or masonry. It need not be a structural element for the building, but, because of its inherent strength, it is generally used as a shear or bearing wall. Material in the wall acts as a repository for thermal energy storage. Benefits of this concept can best be exploited by placing the wall where direct sunlight can be used as a source of heat input. This can be accomplished by using the wall as a partition next to a heavily glazed exterior corridor on the south side of a building. An interior trombe is somewhat less effective because it must be heated by the conditioned air of the facility. Interior trombe walls which contain furnace or fireplace flues can be designed to salvage some otherwise wasted heat.

Various proprietary systems employ the trombe wall concept. Among these are the bead wall and the water wall. In the former, the trombe wall is placed in a position which receives maximum solar insolation during the daytime. A glass panel is placed a few inches away from the exterior face of the wall to increase the solar gain and to contain small polystyrene beads. The beads are blown into the cavity to provide insulation during hours when sunlight is not available, and vacuumed out of the cavity when incoming solar energy is desired. In this manner, absorbed heat is released only to the interior of the building. The water wall is a nonstructural wall that houses containers of water. The high thermal capacity of the water absorbs heat and stores it for release at a later time.

All of the thermal mass concepts can be analyzed with current state-of-the-art principles. Dynamic analyses are required because the phenomenology exploits time variations of heat flow. The approach would be to quantify the effective thermal capacity of the wall based on its component materials. Parameters to be defined would be the effective specific heat, thermal conductivity, and emissivity. This capability is available or could be built into most existing energy analysis computer programs. The M-factor approach described earlier would be an effective design tool for considering the dynamic effects of thermal mass on exterior walls.

The primary benefit of high thermal mass systems is the reduction of total thermal energy requirements by storing heat that would otherwise be wasted. They provide a time lag that reduces the severity of thermal extremes in a manner similar to that observed in earth-sheltered structures. It should be remembered that thermal mass systems are often present in existing buildings and provide benefits which were not considered at the time of construction. Concrete or masonry walls and interior fireplaces are typical examples. The benefits of such systems can be obtained through simple design or construction modifications.

Negative aspects of high thermal mass systems should also be considered. As with most energy-conserving systems, the initial costs would generally be higher than for lightweight construction. This is especially the case when the conventional alternative would be light wood frame construction. High thermal mass systems are generally characterized by reinforced concrete or masonry construction. High mass systems could further add to construction cost in regions of high seismic risk. The additional mass and structural stiffness could increase seismic loads and lead to requirements for stronger, more costly structures. A further disadvantage is that the concepts require moderate to large diurnal or periodic temperature fluctuations. Thus, benefits of the concept may not be significant in extreme arctic or tropical environments.

The Navy could exploit high thermal mass concepts in several ways. Facilities which generally employ low mass structures could benefit from natural thermal storage concepts. Family and troop housing are typical examples. Increased costs of thermal mass systems might be offset by reduced costs for insulation and life-cycle energy costs. Large office or other administrative facilities which would normally employ moderately heavy construction should be evaluated to determine the incremental benefits of increased mass. For example, in reinforced concrete tilt-up construction, a slight increase in wall thickness may not significantly increase construction costs, but could prove extremely beneficial for life-cycle energy savings. In any case, thermal mass effects should be considered in any energy analysis, because benefits may accrue even where they are not explicitly included in the design.

Passive Solar Designs

For the purposes of the present study, passive solar designs are defined as those architectural or structural systems that use the sun to provide heat and light without the use of additional energy input or mechanical devices to transform or distribute the energy. By contrast, active solar concepts would be those which require collectors, concentrators, circulating pumps, heat exchangers, or photovoltaic elements to utilize solar energy. Passive systems are thus more closely related to the basic concept of low energy structures. That is, the form and features of the building contribute to energy conservation. Active solar systems are more appropriately studied in research directed toward energy-conserving mechanical and electrical systems, and these systems will not be discussed here.

Although some specific concepts and approaches will be discussed in this section, passive solar design is more of a philosophy than a formalized methodology. It involves an awareness of the sun's position and its potential to provide beneficial or detrimental energy input to a building. The basic philosophy of passive solar design is to capture and store the sun's energy during periods when the building requires heat input and to capture the sun's light and exclude its heat during periods when additional heat input is not desirable. An excellent general discussion of this philosophy is contained in a book by Edward Mazria (Ref 12). A few of the more specific concepts from that source and others will be discussed here.

One of the most effective means of exploiting solar energy is through beneficial siting and orientation of the building. In general, buildings that are elongated along the east-west axis are more efficient in using the sun's energy. By placing the major portion of the window area on the south side of the building and very few windows on the north, large amounts of thermal energy will be absorbed in the winter. In the summertime, when the sun is at a relatively high angle, few direct rays enter, but reflected light is available. This effect is illustrated in Figure 3. Minimizing the north-facing windows also reduces the heat loss. Thus, the designer who is aware of the benefits and implications of the sun's position at various times of the day throughout the year can properly exploit passive solar energy. Tables giving these data are in Reference 12.

Sites with deciduous trees on the south side also provide passive solar benefits. In the summer, leaves on the trees provide shade to reduce insolation, and in the winter, the lack of leaves permits direct sunlight to impinge on the building. Where such sites are not available, proper landscaping can achieve the same results.

Designs which incorporate a central enclosed atrium can also be used to passively exploit solar energy. One concept which utilizes some mechanical systems is the louvered-atrium concept (Ref 13). In this concept, the structure is built with one or more glass-covered atriums. The glass is protected by an assemblage of highly insulated movable louvers. During the summer time, the louvers open toward the north to admit indirect solar radiation for illumination. In the winter, the louvers open to the south to admit direct radiation for heat and light. During the evening or periods of cold, overcast weather, the louvers are closed to reduce heat loss. The concept is illustrated in Figure 4. Heated air from the atrium can be circulated through the building by convection or mechanical ventilation. This concept permits a building to receive a significant portion of its lighting and heating energy directly from the sun.

A further concept that has applications to new and retrofit construction is the attached greenhouse. This is an enclosure on the south-facing side of the building with walls which are primarily glass or clear plastic. The concept is the same as that used in horticultural or agricultural greenhouses. Extensive glazing permits large amounts of direct solar energy to heat the air within the enclosure. This heated air can be used directly to contribute to the heating requirements of the remainder of the building, or the heat can be absorbed by a thermal wall for storage and future use. Reference 12 indicates that attached greenhouses can distribute 10 to 30% of the total incident heat energy to adjacent building areas. It goes on to say that the payback period for greenhouses is on the order of 1 to 3 years. This estimate is apparently based on residential construction, and part of the dollar saving is assumed to be in reduced food bills as a result of growing produce in the greenhouse. Payback periods for Navy or nonresidential construction would be significantly longer.

Benefits of passive solar design can be significant, and their benefit-to-cost ratios can be especially good for new construction. By simply being aware of passive solar concepts, designers can make minor changes in architecture, building orientation, or landscaping that would have little impact on construction cost, but would contribute significantly to the thermal performance of a building. Most of the concepts described in this section can be evaluated with existing energy use computer codes, and their beneficial effects can be quantified. The beauty of passive solar design is that it uses a "free," renewable energy source. Most specific concepts also employ other energy saving features such as earth-sheltering and thermal mass systems to further enhance their efficiency. A further benefit is that few mechanical systems are required. Thus, high maintainability and reliability are expected to result from such structures.

One of the limitations of passive solar design is that its application is primarily beneficial for new construction. Modifying an existing structure to provide more south-facing windows or a central atrium is generally not economically practical. The only concept that is specifically applicable for retrofit is the attached greenhouse. A second drawback is that all concepts require significant amounts of glass area. Even double- and triple-glazed windows are poor insulators relative to equivalent areas of solid wall, and these areas can lose heat quite rapidly when the sun is not shining. This type of glazing is also relatively expensive. The use of passive solar buildings also impacts the planning process in that such structures require continued access to sunlight throughout their useful life. Adjacent structures cannot be constructed in such a way that they obstruct the path of the sun's rays. Thus, a significant area of land could be encumbered by restrictions on the size and height of facilities adjacent to a passive solar building.

Potential specific Navy applications of passive solar design could include family and troop housing and equipment maintenance facilities. The primary source of energy use in residential facilities is heating and lighting. If a significant portion of this energy demand could be supplied by "free" solar energy, the Navy could achieve significant savings in this area. Equipment maintenance facilities are generally characterized by structures with relatively large floor areas and volumes. Since these facilities require only moderate amounts of light and heat, it may be possible to completely satisfy the energy demands through passive solar design. Purchased energy would only be required for limited applications such as night work or morning warmup in periods of extreme weather. Applications of passive solar principles are possible on nearly all categories of Navy buildings. The extent of the benefits are dependent on facility type, location, and use, and alternative designs employing these principles should be evaluated.

Exploitation of Existing Technology

Reductions in energy use of buildings does not necessarily require new technology. Many concepts, materials, and construction practices that are in common use can be exploited. In many cases, just the proper execution of present practices can lead to measurable improvements in energy usage. This section will discuss how existing technology and simple extensions of that technology can be exploited to achieve more energy-efficient structures.

The National Association of Home Builders Research Foundation has incorporated many elements of existing technology into a demonstration residence for the U.S. Department of Housing and Urban Development (Ref 14). The residence is a nominal 1,200-ft^2, 3-bedroom house with a basement. Among the general energy conserving features are:

a. compact floor plan
b. vestibule entrance
c. 7-foot 6-inch ceiling heights
d. energy-efficient fireplace and appliances
e. various passive solar concepts
f. extensive insulation
g. extensive measures to reduce infiltration

Wood frame construction was used with 2 x 6s at 24 inches on center to provide room for R-19 wall insulation. A 6-mil polyethylene vapor barrier was placed inside the insulation throughout the house. This continuous barrier significantly decreases infiltration of exterior air. The design uses R-38 insulation above the ceiling, R-11 adjacent to below grade basement walls, and R-19 on exposed exterior walls. Windows are triple glazed. A typical wall section is shown in Figure 5. The energy-efficient residence is expected to require 1/3 to 1/2 less energy than an equivalent house which meets or exceeds current standard practice.

A second approach to exploiting existing technology is the superinsulated building (Ref 15). Initial efforts for this approach are also centered on residential construction. The premise is that relatively large amounts of insulation and infiltration control can reduce energy requirements for space heating and cooling to almost zero. Typical superinsulated houses have R-values of 40 for walls, 60 for ceilings, and 40 for floors. Large insulation value in exterior walls is achieved by using double walls to provide sufficient space for insulation material. Overall design generally includes attention to passive solar principles, use of 6-mil polyethylene vapor barriers, and vestibules on exterior doors. These houses also employ air-to-air heat exchangers which permit stale, conditioned air which is leaving the house to transfer heat to or from fresh, unconditioned air that is entering the house. By using this active air exchange system, incoming fresh air is preconditioned to reduce heating and cooling requirements. Some of the key construction details are shown in Figure 6.

Economic benefits of superinsulated construction may vary greatly. The severity of local climate, the extent and number of concepts implemented, and the type and cost of energy sources are critical factors. Initial costs can vary from 1 to 8% above conventional building costs, and the payback period varies from 1-1/2 to 15 years depending on the values of the critical factors. Thus, localized energy use and economic analyses are needed to evaluate the economic benefits of such systems.

A relatively basic approach to exploiting existing technology to achieve low energy structures is through energy conscious architecture (Ref 16). Energy utilization in a structure should be considered in the conceptual stages of design. Factors which impact the passive solar performance such as orientation, fenestration, and exterior color should be exploited wherever possible. In climates where thermal mass benefits can be significant, the architectural concepts should favor masonry or reinforced concrete structures over wood or metal frame construction. Designers should keep their minds open to the option of using earth-sheltered designs where geographical and functional conditions permit. Designers should also be aware of the latest and most effective products for insulating, sealing, and glazing buildings. By simply being aware of the qualitative impact that design can have on the energy efficiency of buildings, designers can make significant strides toward achieving low energy structures.

Energy considerations need not dominate the design process. They must be considered in their proper context. Energy conservation is only one of several methods for reducing the total life cycle cost of a building. Concepts for which a rational analysis with properly escalated energy costs should not be implemented if they do not produce savings in life-cycle costs. Functional and mission requirements of facilities must also be considered.

The primary benefit of exploiting current technology is the low technical and economic risk. Extensive data are available on past performance of the products and designs, and costs are easily predictable. Building contractors do not need new skills or equipment to implement the concepts, so chances of construction errors are reduced. Since the products and techniques are familiar to contractors, initial costs may be lower. Bids may not be inflated by contingency factors. A further benefit is that the technology is available now, and has in some cases been available for many years. No development time or cost is necessary to implement these concepts.

Limits do exist on the extent to which current technology can improve the energy efficiency of Navy buildings. Significant savings can be achieved in the short run, but these savings only represent a reduction in the waste that has occurred due to poor design. Once the waste has been eliminated, the need to achieve true savings remains. Designers may become complacent and feel that current technology is adequate. This attitude may lead to a resistance to change. Thus, designers must exploit existing concepts to their limits, but they must also be receptive to new concepts.

The Navy can exploit current technology for energy conservation in virtually all of its shore facilities. The first step that was taken in this direction was the publication of interim design criteria for energy conservation (Ref 17 and 18). These publications describe commercially available equipment and systems which can be implemented to improve the energy efficiency of new and existing buildings. They also specify general criteria for energy conscious design. Publications such as these will help to make architects and engineers more aware of concepts for improved low energy structures.

SUMMARY

This report has discussed various concepts for energy conservation in Navy shore facilities which can be achieved through architectural and structural design decisions. These concepts include earth-sheltered structures, thermal mass concepts, passive solar designs, and exploitation of existing technology. Advantages and disadvantages of the systems were discussed in qualitative terms. Where possible, specific data and equations were presented to show how the benefits could be evaluated for specific designs. Sufficient information is available here and in the references to permit a designer to evaluate any of the concepts for applicability to a specific design case.

Future efforts for this project will be directed toward maintaining contacts with researchers and builders of low-energy structures and toward evaluating the performance of energy-conserving concepts implemented by NAVFAC. Among the latter is a partially bermed dental clinic which was recently completed at Naval Air Station, North Island, San Diego, and the planned MESO Environmental Quadraplex family housing units at the Marine Corps Air Station, Fallon, Nev.

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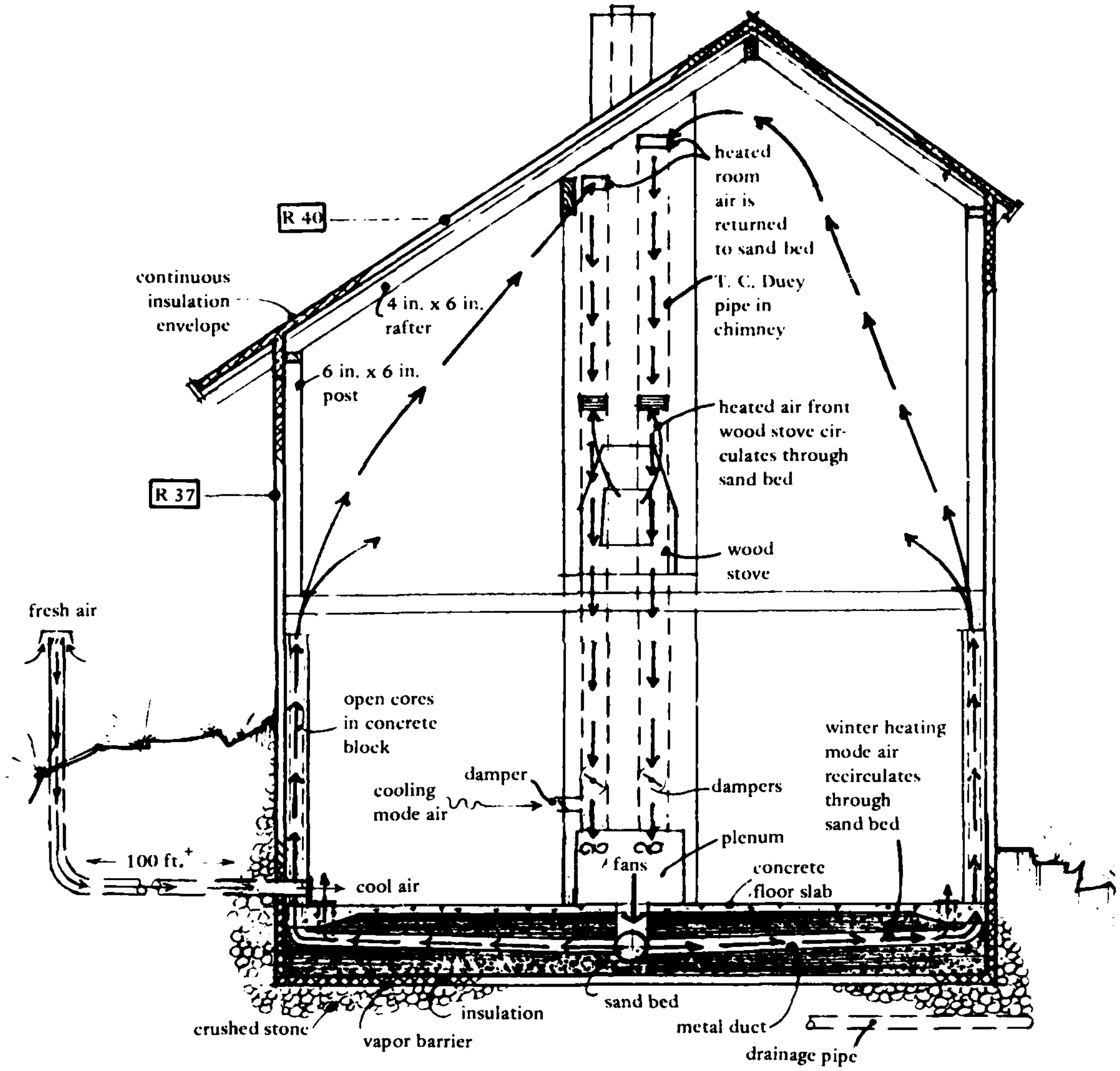
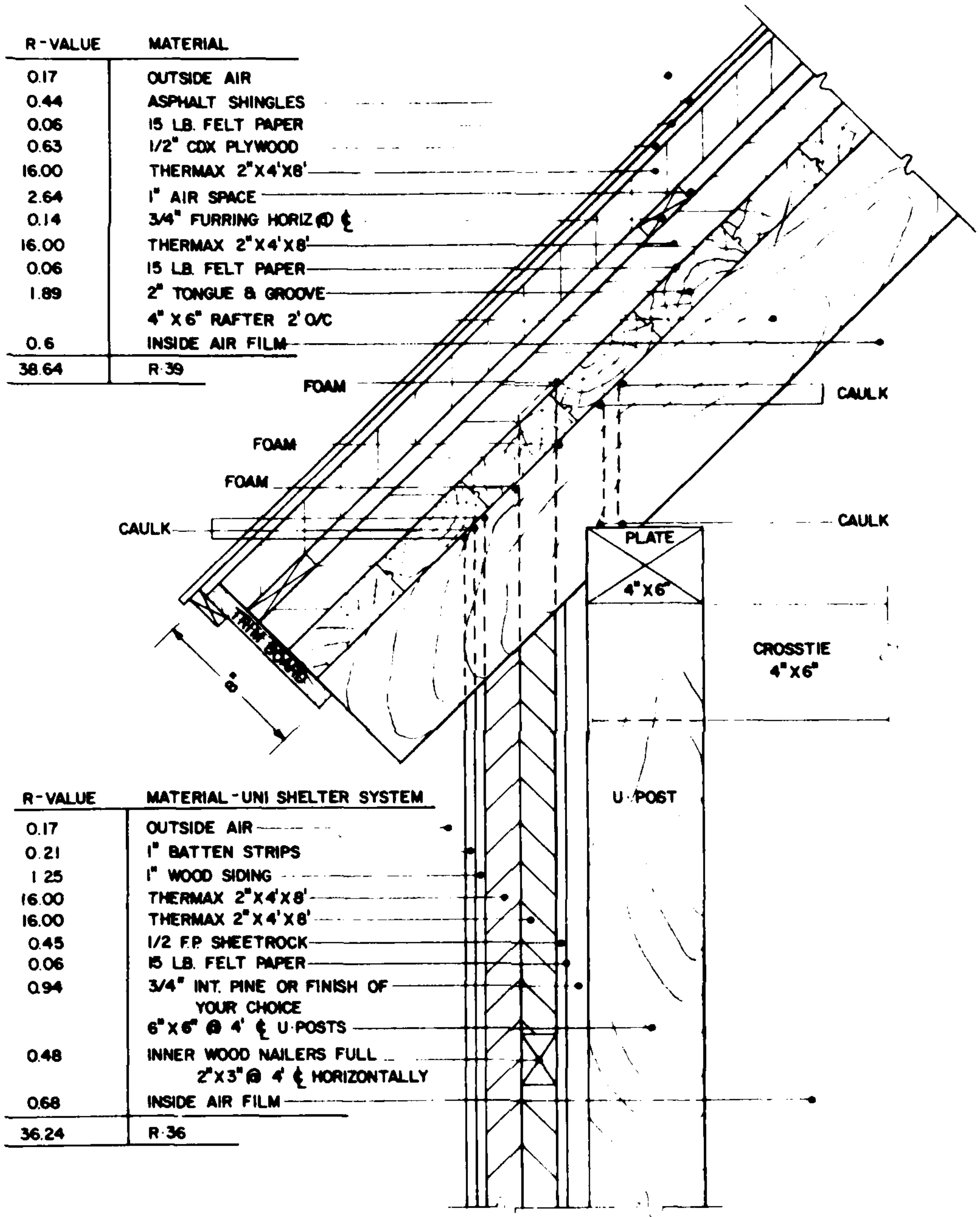


Figure 1. Diagrammatic section of LER house.



R-VALUE	MATERIAL
0.17	OUTSIDE AIR
0.44	ASPHALT SHINGLES
0.06	15 LB. FELT PAPER
0.63	1/2" CDX PLYWOOD
16.00	THERMAX 2"X4'X8'
2.64	1" AIR SPACE
0.14	3/4" FURRING HORIZ @ ¢
16.00	THERMAX 2"X4'X8'
0.06	15 LB. FELT PAPER
1.89	2" TONGUE & GROOVE
	4" X 6" RAFTER 2' O/C
0.6	INSIDE AIR FILM
38.64	R-39

R-VALUE	MATERIAL-UNI SHELTER SYSTEM
0.17	OUTSIDE AIR
0.21	1" BATTEN STRIPS
1.25	1" WOOD SIDING
16.00	THERMAX 2"X4'X8'
16.00	THERMAX 2"X4'X8'
0.45	1/2 F.P. SHEETROCK
0.06	15 LB. FELT PAPER
0.94	3/4" INT. PINE OR FINISH OF YOUR CHOICE
	6"X6" @ 4' ¢ U-POSTS
0.48	INNER WOOD NAILERS FULL 2"X3" @ 4' ¢ HORIZONTALLY
0.68	INSIDE AIR FILM
36.24	R-36

Figure 2. Roof system detail.

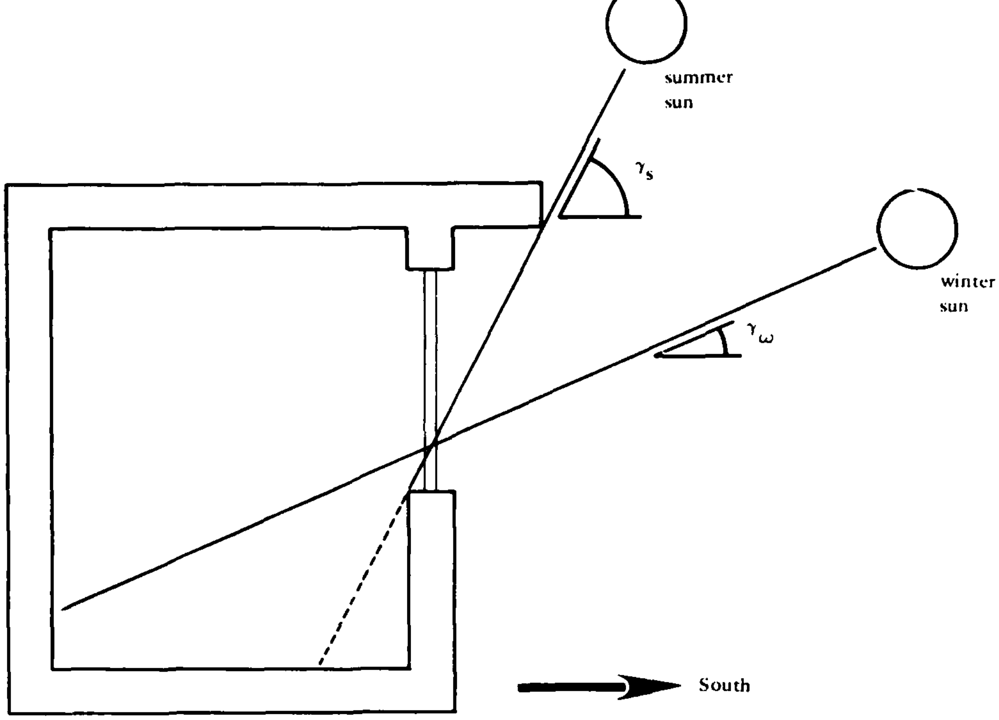


Figure 3. Variation of sun's rays for south-facing windows.

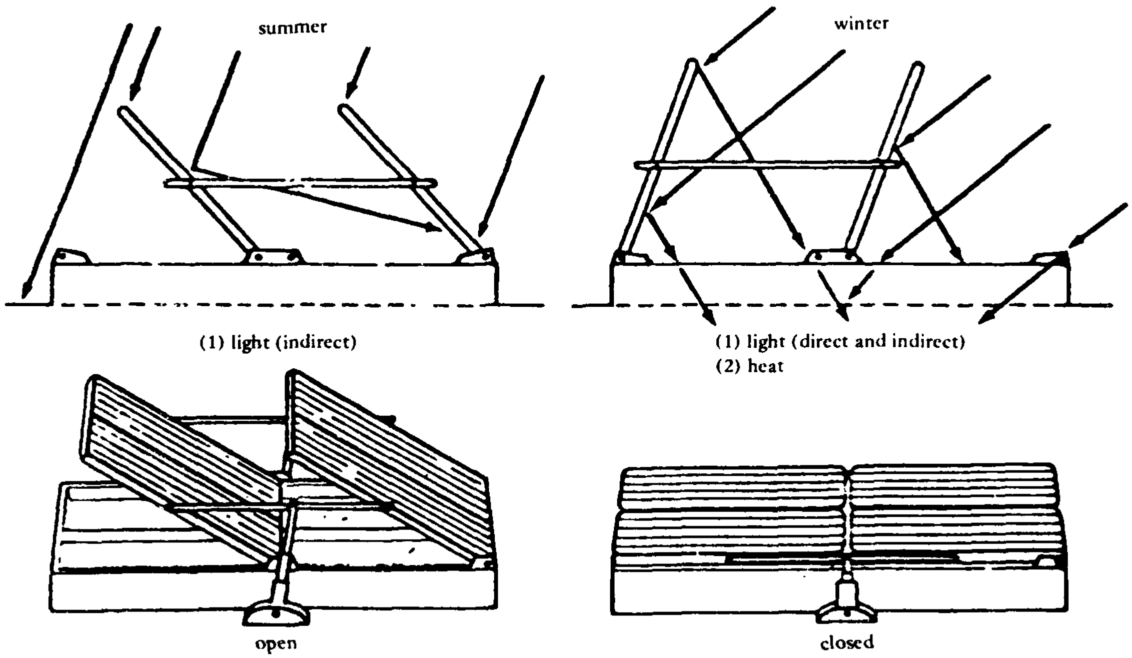


Figure 4. Louver Atrium concept.

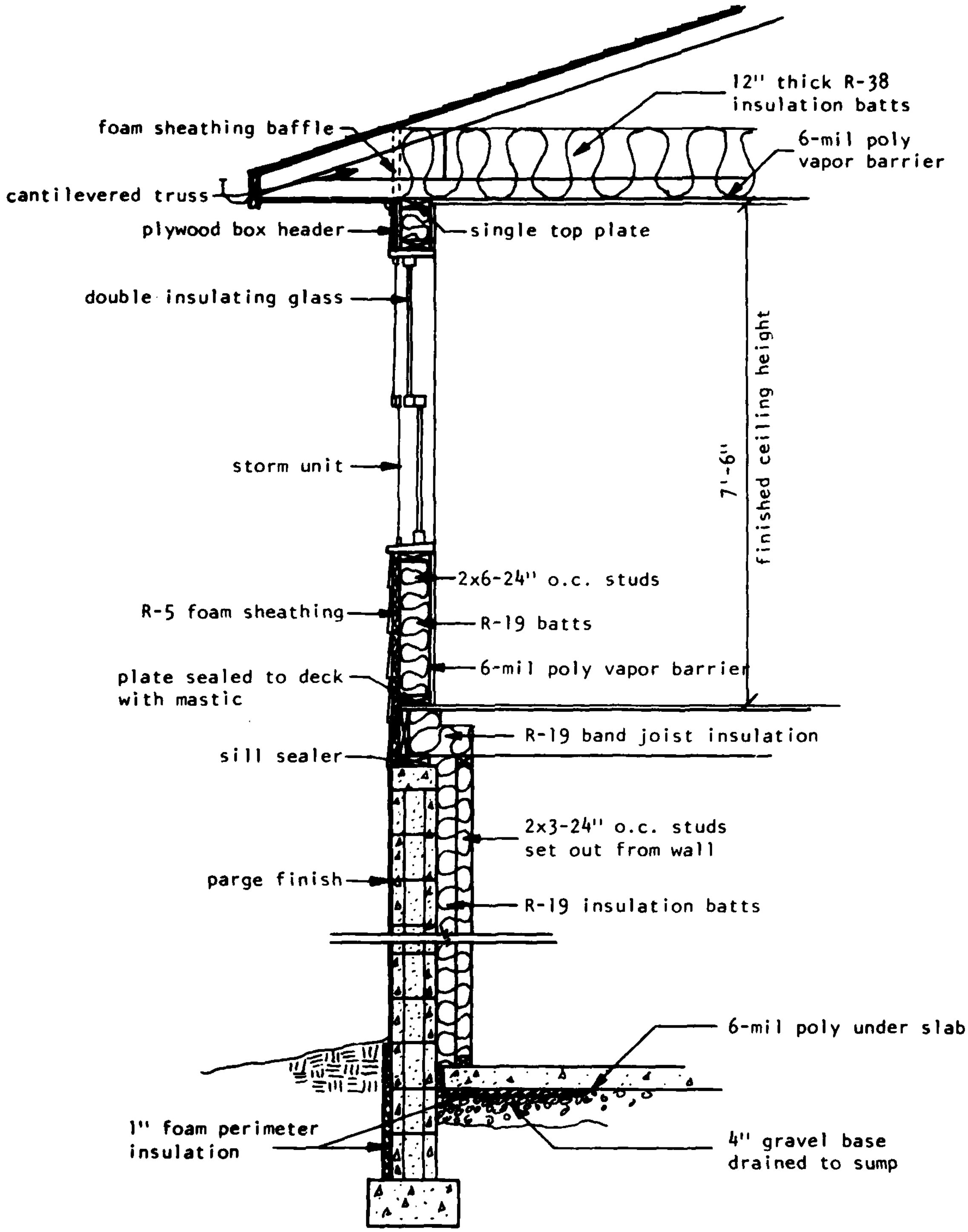


Figure 5. Energy efficient residence.

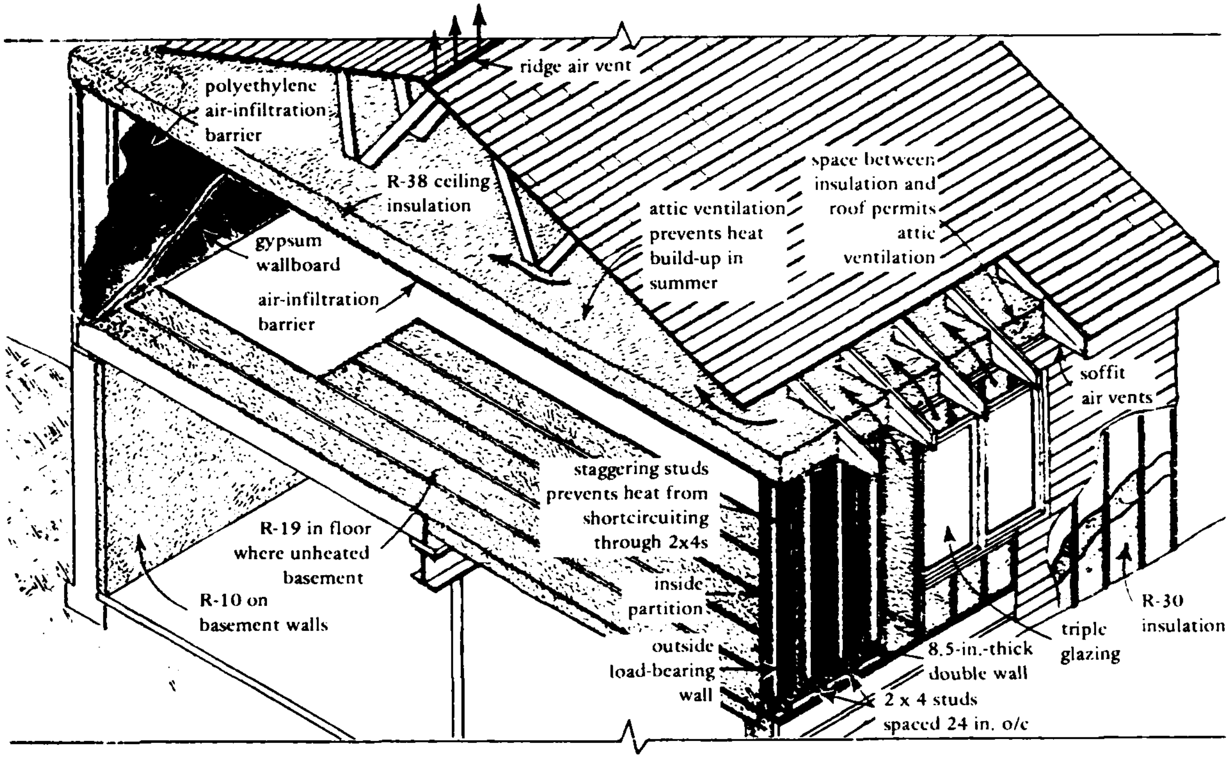


Figure 6. Typical superinsulated house.

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